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Cost and Performance Report

(WP-0404)

Demonstration of Diesel Engine Air Emissions Reduction Technologies

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COST & PERFORMANCE REPORT
ESTCP Project: WP-0404

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

Page

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
ATC	Aberdeen Test Center
B20	20% Biodiesel by Volume, 80% Petroleum Diesel by Volume
BAT	best available technology
CAA	Clean Air Act
CARB	California Air Resources Board
CBD	Central Business District
CCR	California Code of Regulations
CES	Cummins Emissions Solutions
CFR	Code of Federal Regulations
CO	carbon monoxide
CO_2	carbon dioxide
CSF	catalyzed soot filter
DENIX	Defense Environmental Network & Information Exchange
DNPH	dinitrophenylhydrazine
DOC	diesel oxidation catalyst
DoD	Department of Defense
ECM	electronic control module
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
ESW	Environmental Solutions Worldwide, Inc.
FE	fuel economy
Fed EPA No. 2	Low Sulfur Diesel Fuel No. 2 (sold outside California and containing up to 500 ppm of sulfur)
FID	flame ionization detector
g/mile or g/mi	grams per mile
GC	gas chromatography
GC/MS	gas chromatography/mass spectrometry
HAP	hazardous air pollutant
HC	hydrocarbon
HPLC/UV	high performance liquid chromatography/ultraviolet
kPa	kilopascal
mph	miles per hour

ACRONYMS AND ABBREVIATIONS (continued)

NAVFAC	Naval Facilities Engineering Command
NDIR	non dispersive infrared
NMHC	non-methane hydrocarbon
NORAD	North American Air Defense Command
NOx	nitrogen oxides chemical compounds, including NO and NO2
NREL	National Renewable Energy Laboratory
PAH	polycyclic aromatic hydrocarbon
PM	particulate matter
ppb	parts per billion
ppm	parts per million
PuriNOx	Proprietary Water / Diesel Emulsified Fuel
RPF	robust particulate filter
THC	total hydrocarbon
UCR	University of California, Riverside
µg/mL	micrograms per milliliter
ULSD	ultra-low-sulfur diesel (<15 ppm)
VOC	volatile organic compound

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Furthermore, we wish to thank the National Renewable Energy Laboratory (NREL) and University of California at Riverside (UCR) personnel for performing the emissions measurements and the use of their facilities. The project had excellent support from the host field test sites: Cheyenne Mountain Air Force Station, Aberdeen Test Center (ATC), and Camp Pendleton. We wish to extend our thanks to personnel at those sites: Monte McVay from Peterson Air Force Base (AFB) and Nancy Wellhausen of Tetra-Tech for their helpful cooperation in conducting the tests at the Cheyenne Mountain Air Force Station, Mitch Maynard and Bill Martine at Camp Pendleton, and Jason Jack and Steven Tapp at ATC.

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Technical material contained in this report has been approved for public release.

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

Diesel engines are widely used throughout the Department of Defense (DoD) for powering tactical and nontactical vehicles and vessels, off-road vehicles and equipment, engine-generator sets, aircraft ground-support equipment, and a variety of other applications. Although diesel engines are known to emit several types of pollutants into the atmosphere, human health concerns regarding the penetration of the small particulate matter (PM) into the deeper regions of the lungs have greatly increased interest in diesel PM emissions in the recent past. PM emissions are regulated as a criteria pollutant by the National Ambient Air Quality Standards established by the Clean Air Act (CAA).

Although most regulations are directed at the certification of new diesel engines, increasingly, emphasis is being placed on in-service engines. The California Air Resources Board (CARB) has issued PM control regulations requiring the retrofit of school buses, garbage trucks, and off-road vehicles. To address these compliance requirements, many exhaust gas treatment devices are coming onto the market, but the selection of the optimal one (which also must meet the approval of applicable regulatory bodies) depends on several factors that must be evaluated for each application.

This project demonstrated two diesel engine exhaust gas treatment devices believed to have the potential for assisting the DoD in meeting applicable PM regulatory requirements. In both cases, the technology consists of a high-temperature filter designed to remove the PM from the exhaust stream. The difference between the two filter designs involves the filter pore size and thus their ability to capture the PM emissions (50% vs. 85% PM reduction), as well as their method for regeneration. Both filters include the ability for in-use regeneration, the difference is the fact that one is regenerated passively, using only the heat of the engine, while the other is actively regenerated using direct fuel injection into the filter. These two technologies were tested on eight DoD operated diesel engines at three DoD sites—ATC, Camp Pendleton, and Cheyenne Mountain Air Force Station. The test periods varied from a few months to over one year.

1.2 OBJECTIVES OF THE PROJECT DEMONSTRATION

The primary objective of this project is to demonstrate that the two tested technologies will be capable of reducing diesel engine PM emissions by at least 50%, and to demonstrate that the technologies are sufficiently robust to provide years of trouble-free service. In addition to these primary objectives, other objectives included significant reductions in carbon monoxide (CO), hydrocarbon (HC), and hazardous air pollutant (HAP) emissions; maintaining vehicle fuel economy and drivability; and demonstrating the ease of installing the technologies.

For the Environmental Solutions Worldwide, Inc. (ESW) particulate reactor technology, all emissions reductions, drivability, installation, and reliability performance objectives were met. For the Cummins, Inc. robust particulate filter (RPF), installation and reliability performance objectives were not met. The emissions control performance objectives for the RPF filter were not measured since the other performance objectives were not met.

1.3 REGULATORY DRIVERS

Mobile-source diesel emissions are regulated by both federal (40 Code of Federal Regulations [CFR] 86, 89) and California (13 California Code of Regulations [CCR] Chapter 3) equipment and vehicle standards. Those standards are applied to equipment and vehicles at the time of manufacture. In the last 8 years, the Environmental Protection Agency (EPA) has pursued a program to dramatically tighten these regulations, including a 90% reduction in permitted PM emissions between the years 2000 and 2007. Likewise, the EPA has also pursued a program to dramatically tighten the regulations for non-road diesel engines. These regulations, unlike their on-road counterparts, are based on the size of the engine, with larger engines having tighter standards.

In October 2000, CARB finalized their Risk Reduction Plan to reduce PM emissions from diesel-fueled engines and vehicles. That plan calls for the use of ultra-low-sulfur fuels and retrofit requirements for in-use engines or the replacement of them. In support of their Risk Reduction Plan, CARB has already promulgated several regulations requiring the retrofit of in-service diesel engines. Of particular importance to the DoD is their recent regulation that requires off-road diesel powered vehicles to be retrofitted or replaced by the end of 2010.

1.4 DEMONSTRATION RESULTS

The results of testing of the ESW filter showed that use of this filter will decrease CO, HC, PM, and HAP emissions, thus meeting the performance objectives set out in the Demonstration Plan. Backpressure, fuel usage, drivability, reliability, and installation requirements were also met sufficiently well so that this unit can be recommended for use with suitable DoD engine applications.

The RPF filter technology, however, performed irregularly in demonstration testing leading to frequent filter clogging and the subsequent removal of several test units prior to completion of the project. The filter manufacturer believes that this technology could be effectively applied as a retrofit application as long as strict guidelines are in place for evaluating the duty cycle of the target vehicle. However, significantly more testing would be needed to verify the technology. Based on this poor performance, Cummins Emissions Solutions (CES) has decided not to offer the RPF technology in the retrofit market.

1.5 STAKEHOLDER/END-USER ISSUES

The purchase of diesel filters represents a significant and many times unplanned cost to government diesel-powered equipment and vehicle fleet managers. These managers are faced with a multitude of choices in meeting current and proposed new regulations for reducing diesel PM emissions. Unfortunately, many of the commercial products available to address this problem are not suitable for common DoD engine duty cycles. Other products, although effective, may not meet government needs for maintainability and durability. Government decision makers therefore need an independent, informed resource such as the results from this project to assist them with the selection of appropriate diesel engine emissions control technologies.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

2.1.1 Environmental Solutions Worldwide, Inc. (ESW) Particulate Reactor

The ESW filter is a newly developed diesel engine high-temperature exhaust gas treatment filter designed to reduce diesel engine PM emissions. Normally, the filter is installed in place of the muffler. Although the technology is currently commercially available, its use in commercial fleets is limited due to its short time of exposure in the marketplace.

The ESW diesel oxidation catalyst filtering technology was developed to reduce PM emissions by up to 60%. This is twice the reduction of traditional diesel oxidation catalysts (DOC) but lower than the 90% reduction possible with a diesel particulate filter such as the RPF filter. While traditional diesel oxidation catalysts reduce CO, HC and the soluble portion of the PM emissions, the ESW filter also catalytically oxidizes a portion of the black (inorganic) carbon emissions. This reduction is accomplished by use of a proprietary flow-through low backpressure filtering process with large pore sizes where the filter media is coated with the catalyst material. In the filter, the collected engine exhaust soot is periodically oxidized. This occurs when the filter is heavily loaded with soot and a high engine exhaust temperature occurs. No additional heat source is required to initiate this regeneration process.

The ESW filter has been certified by the CARB as a Level II diesel emissions control device. Diesel filters certified at this level have been verified to reduce PM emissions by at least 50%. A photograph of the filter media is shown in Figure 1.

Figure 1. ESW Particulate Reactor Cutaway.

The ESW filter was developed for both the new and retrofit diesel engine market for engines that do not maintain high exhaust temperatures for significant portions of their duty cycles and for

applications where a >85% reduction in PM emissions (i.e., CARB Level III certification) is not required. It was designed primarily for new off-road equipment as well as for the retrofit of existing on-road vehicles. This technology is suitable for use with current EPA-approved off-highway diesel fuel containing <500 parts per million (ppm) of sulfur. Its performance will, however, improve when on-highway ultra-low-sulfur diesel (ULSD) containing <15 ppm of sulfur is used.

Although the ESW filter does not offer a performance level equivalent to the RPF, a Level III emission control filter, it does offer several economic and technological advantages. Once in full commercial production, it is expected that the ESW filter will be priced approximately 25% less than Level III emission control devices for similar applications. Further reducing ESW filter lifetime costs is the fact that no scheduled maintenance is required; it is a completely passive filter requiring no computer, other controls, or utilities. It is also a much more robust filter than almost any Level III device and will be able to withstand many of the harsher, clogging environments that DoD equipment is typically subjected to. Finally, ESW filters will self-regenerate at lower engine load conditions than most Level III filters.

2.1.2 Robust Particulate Filter

Cummins has developed the RPF to reduce PM emissions from diesel engines by up to 90%. The RPF system, as shown in Figure 2, was designed for and commercially used in 2007 new Cummins engines. The RPF system consists of four major parts: a catalyzed soot filter (CSF), a DOC, a fuel injection system, and the electronic control system. The CSF removes PM from the exhaust gases using a wall-flow filtering process with very small pore sizes. Periodically, high exhaust temperatures from either a highly loaded engine or caused by fuel injected directly into the exhaust (a.k.a. *dosing*), causes the soot accumulated on the catalyzed surface of the CSF to oxidize. This process, producing CO and carbon dioxide (CO_2), is termed "regeneration." The DOC installed upstream from the CSF catalytically oxidizes the CO and HC species in the exhaust as well as the soluble portion of the PM emissions to CO_2 and H_2O. The fuel injection system periodically injects fuel into the exhaust system upstream of the diesel oxidation catalyst where, at adequate temperatures, the injected fuel is also oxidized to provide sufficient thermal energy to the CSF to cause the soot to oxidize and regenerate the CSF. The proprietary electronic control system determines when, and if, the fuel injection system will be activated. This determination is made by using a differential pressure measurement from across the CSF as well as by other proprietary engine operational parameters.

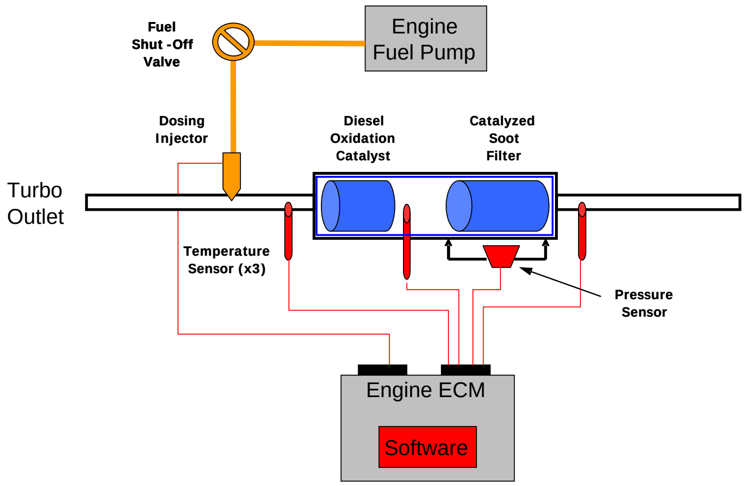

Figure 2. Robust Particulate Filter.

The RPF technology was developed for the new diesel engine market, although for this project it was used for retrofit applications. It was designed primarily for on-road vehicles that, by virtue of the exhaust gas temperatures, do not maintain sufficiently high exhaust temperatures during their duty cycles to provide satisfactory "passive" regeneration of the filters. An advantage of this filter, compared to competing technologies, is that it is suitable for use with current EPA-approved off-highway diesel fuel containing up to 500-ppm of sulfur. However, the technology's performance improves when fuels with lower sulfur levels are used. This technology represents the next generation of the CSF that was demonstrated in a previous Environmental Security Technology Certification Program (ESTCP) project (see Reference 1). In that project, it was found that a passive CSF is appropriate only in a very limited number of applications where the engine has high exhaust temperatures for a significant portion of its duty cycle.

2.2 PROCESS DESCRIPTION

For this project, both the ESW and RPF technologies have been designed to replace the muffler in the vehicle's exhaust system. The new hardware was individually sized for each test vehicle to ensure that the systems could handle the full exhaust flow rate. It was expected that each system installation could be completed within 8 hours using specially trained diesel mechanics. These technologies have also been designed so that no vehicle operator actions are normally required. On-board diagnostics capabilities were installed to indicate system performance and condition. The vehicle operator needs only to be able to identify a problem so that the system could be repaired by qualified maintenance personnel. There are no health or safety requirements for this hardware, except if filter cleaning is required. Based on this ease of use, only minimal operator training was required.

The performance targets for the technologies are outlined in Table 1. The most important target was to reduce PM emissions by 50%, yet be sufficiently robust to provide years of service with little or no maintenance. (These requirements are also part of those listed in Federal and

California equipment and vehicle standards [40 CFR 86, 89, and 13 CCR Chapter 3, respectively]).

2.3 PREVIOUS TESTING OF FILTER TECHNOLOGIES

2.3.1 ESW Particulate Reactor

Cummins Engine Company has satisfactorily completed “hot” rig/shaker (off engine/vehicle) testing, engine dynamometer testing, and vehicle field-testing on the ESW filter. Rig testing is the term used to describe off-engine testing, and shaker testing involves mounting a component or subsystem on a shaker table that vibrates in one axis or more (vertical, axial, or radial) at loads and frequencies determined to be common and critical to the application in which the component or subsystem will be used. The term “hot” means that the component was heated to operating temperature by running hot air through it to simulate exhaust gas conditions.

Engine dynamometer testing of the ESW filter consisted of system performance and mechanical development tests. Emissions tests were conducted on two engine families: the 5.9 liter Cummins B Series and 7.3 liter Navistar T444E engine, using low sulfur (less than 350 ppm) diesel fuel. These tests showed PM reductions greater than 50% by mass.

In addition to the above described rig and engine test cell testing, the ESW filter also underwent extensive field testing beginning in 2003. Seventeen engines in both on- and off-road applications were fitted with an ESW filter and used for the field-testing. Off-road applications included a John Deere diesel-powered generator and a Cummins QSK19-powered crane. On-road field testing included a pickup and delivery vehicle, 10 school buses, two Mack refuse trucks, and two transit buses.

2.3.2 Robust Particulate Filter

During a previous ESTCP project (see Reference 7.1) performed by the Naval Facilities Engineering Command (NAVFAC) Engineering Service Center, as well as in other demonstrations, passive soot filters have been extensively tested in both engine test cells and on numerous test vehicles. The active RPF represents the latest generation of the CSF technology. The initial field testing of a passive CSF technology was conducted in 1998 on eight urban buses operated by the New Jersey Transit Authority. Those results showed CSF lifetimes of greater than one year (>100,000 miles) and PM emissions reductions of greater than 80%. Some soot filter failures were also noted during this program, indicating the need for manufacturing improvements, the importance of monitoring the condition of the soot filter and performing routine maintenance. Those tests were followed by the ones reported in Reference 7.1, which demonstrated both the importance of knowing the exhaust temperature histories from the diesel engines, and the wide range of these histories that apply to DoD diesel engines.

Because of the limited applicability of the passive CSF technology, Cummins developed the RPF technology as their primary strategy for meeting the year 2007 new heavy-duty diesel engine PM emissions limits. Internal Cummins testing of this technology began in 2004 and continued through the fall of 2006. This extensive testing program consisted of bench/rig testing, engine test cell testing and on-road vehicle testing. Validation testing for 2007 engine applications was divided into both subsystem (controls, DOC, fuel doser, and particulate filter) and total system

performance testing. The total system performance testing consisted of active regeneration testing, back pressure mapping and performance measures, full load endurance testing, 1,500-hour start/stop cycle testing, accelerated aging/life tests, noise testing, complete thermal fatigue analysis, as well as summer and winter field testing using Cummins-operated heavy-duty trucks.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The ESW technology demonstrated a minimum 50% reduction in PM emissions while the RPF system was designed for a 90% reduction. This is an improvement over a DOC that reduces the PM emissions only by 30%. The DOC removes only the soluble organic soot compounds whereas the demonstrated technologies also reduce a portion of the soot's black carbon.

For potential users, the ESW filter offers the advantage of being commercially supported by a major diesel engine manufacturer. The ESW technology also offers the advantage of requiring no engine operator actions and of being suitable for use for a wide range of applications. Based on its poor performance in this demonstration, Cummins has decided not to make the RPF filter a commercial product for the retrofit market; therefore, this report will provide no further discussions of its advantages and limitations.

The ESW technology has been designed to meet the CARB Level II requirement. Given this design, the technology is expected to compete in those vehicles' (on- or off-road) retrofit and new off-road and stationary engine market segments where both the user and the applicable air pollution regulatory agency would be satisfied with a 50% reduction in PM emissions. Unlike some competing technologies, the ESW technology is suitable for use with low sulfur fuel. It does not require the use of ULSD.

The major cost categories for diesel engine emissions treatment technologies are the purchase cost, the installation cost, maintenance, and the operating costs. The primary cost driver for the ESW unit is the use of precious metal in the catalyst that is used to assist in burn-off of accumulated soot and regeneration of the filter. This cost, although significant, is comparable to those for competing diesel after treatment technologies.

The primary limitations on the use of the ESW technology are the engine duty cycle and the fuel sulfur level. In order to provide PM reductions over a long period of time, the ESW filter periodically needs to regenerate itself by causing the soot collected to be oxidized to CO_2 by a catalytic oxidation process. To initiate the oxidation, a high exhaust temperature excursion is required, although, in the tests conducted in this project, that temperature excursion was extremely modest. To ensure proper operation, ESW recommends that the engine operates with an exhaust temperature above 300°C for 7% of the duty cycle.

Like the engine exhaust temperature, the fuel sulfur level also limits the applicability of this technology. During the oxidation reaction on the catalyst, fuel sulfur compounds are oxidized into solid sulfates, a form of ash. Since the ESW filter is a CARB Level II certified device, the pore size of the catalyst will allow the majority of this ash to simply pass through into the atmosphere whereas a Level III filter, such as the RPF filter, would retain this ash and need to have it periodically removed in order to maintain low filter backpressures. Within these limits, the ESW is designed to be applicable for fuels having sulfur levels < 500 ppm.

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Table 1. Performance Objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Quantitative	Backpressure	20-34 kilopascal (kPa) of backpressure	Yes
	CO emissions reduction	60% reduction	ESW – Yes RPF – Not measured
	Fuel economy	Less than 2% decrease	ESW – Yes RPF – Not measured
	HC emissions reduction	60% reduction	ESW – Yes RPF – Not measured
	PM emissions reduction	50% reduction	ESW – Yes RPF – Not measured
	HAP* emissions reduction	50% reduction	ESW – Yes RPF – Not measured
Qualitative	Drivability	Maximum one driver report of drivability issue	ESW – Yes RPF – Yes
	Installation	8 hours per installation	ESW – Yes, RPF – No
	Reliability	Maximum one breakdown caused by pollution control device	ESW – Yes, RPF – No

*HAP = hazardous air pollutant

3.2 SELECTING TEST SITES/FACILITIES

DoD test sites were selected to provide a broad array of DoD on-highway vehicles. Also important to the test site selection process was their proximity of the test vehicles to project personnel. A primary consideration in the selection of the test units was the vehicle operating profile. Here, emphasis was placed on vehicles that normally operated at medium to high load levels with long operating times. Secondary considerations included ease of installation of the pollution control hardware and the number of similar units in the DoD inventory.

A total of eight vehicles at three test sites were selected for demonstrating the ESW and RPF filters. Since one engine may be operated under different conditions (e.g., different driving routes) compared to the rest of a fleet, duplicate engine applications were included where possible. Test sites, an identification of the proposed demonstration units, and the technology installed on each demonstration unit are shown in Table 2.

Table 2. Diesel-Powered Vehicles to be Demonstrated.

Demonstration Site	Vehicle	Control Technology
Marine Corps Base, Camp Pendleton, California	Ford L9000 truck Thomas bus International 7600 truck Ford F Series stake truck	Robust particulate filter Robust particulate filter ESW particulate reactor Robust particulate filter
Cheyenne Mountain Air Force Station, Colorado	Thomas bus Thomas bus	ESW particulate reactor ESW particulate reactor
U.S. Army Aberdeen Test Center, Aberdeen Proving Grounds, Maryland	Ford F350 pickup truck Navistar 4700 panel truck	ESW particulate reactor Robust particulate filter

3.3 TEST SITE/FACILITIES HISTORY/CHARACTERISTICS

The demonstration vehicles were located at the DoD facilities described below:

Marine Corps Base, Camp Pendleton, California, is the site of the Corps' largest amphibious assault training facility, encompassing 17 miles of Southern California coastline and 125,000 acres. The base has a population of nearly 40,000 marines and sailors. As such, nearly every type of equipment in the Marine Corps inventory is located at this facility. As a functioning training command, the equipment is used almost daily for training and transportation purposes. The trucks and bus selected for the demonstration are used primarily for trips between various Marine Corps and Navy training activities within Southern California as well as for on-base use. Many of the vehicle trips were through the California desert, a very hot and dry environment.

Cheyenne Mountain Air Force Station, Colorado Springs, Colorado, is buried 2,000 feet under Cheyenne Mountain at an elevation of over 7,000 feet. The facility is situated in underground tunnels that were bored out of the mountain. The air station is a top-secret combat operations center formerly known as the North American Air Defense Command (NORAD). The station contains equipment that provides warning of missile or air attacks against North America and can serve as the focal point for air defense operations in the event of an attack. The station's mission is to provide Canadian and U.S. National Command authorities with accurate air, space, missile and nuclear detonation information. The major units of the station are the North American Aerospace Defense Command, U.S. Space Command, and Air Force Space Command. To access the main operational areas, diesel-powered vehicles are used in the underground tunnels. Exhaust from these vehicles is the major source of contamination for the facility's air handling system. The Thomas buses selected for the demonstration are used to transport workers down the main access tunnel.

U.S. Army Aberdeen Test Center (ATC), Aberdeen Proving Grounds, Maryland, is an East Coast temperate-climate proving ground encompassing 57,000 acres of land and water. It is the DoD's lead test center for land vehicles, guns and munitions, and live-fire vulnerability and lethality testing. After more than 80 years, ATC has developed into a world-class, all-purpose test center operating as an outdoor laboratory. The comprehensive array of capabilities, unique facilities, simulators and models at ATC, combined with an experienced scientific and technical work force, enable testing and experimentation on items ranging from components to entire systems. To support its testing mission, many of the diesel vehicles used by the DoD are found on Aberdeen

Proving Grounds. The Ford F350 pickup truck selected for the demonstration is used primarily to support the long distance transport of oversized equipment. The Navistar 4700 panel truck is primarily used to support on-post weapons testing.

All eight vehicle demonstration vehicles are operated by DoD activities in support of their missions. These units utilize diesel engines supplied by various manufacturers and were sold between 1992 and 2003. None of these engines was equipped with aftermarket air pollution control devices. Some of the engines proposed for the demonstration produced visible soot during operation, making them prime candidates for retrofit of pollution control devices.

3.4 PHYSICAL SETUP AND OPERATION

To verify that the exhaust temperature profiles would meet the minimum duty cycle requirement for each of the demonstrated technologies, six of the candidate test vehicles were instrumented for a 1-2 week period. These "screening tests" included measurements of hours of vehicle use as well as average and maximum exhaust temperatures. The project team did not instrument the Camp Pendleton Thomas buses because sufficient exhaust temperature data was available from the previous ESTCP project (Reference 7.1). Results from this pre-demonstration testing are shown in Table 3.

Table 3. Pre-Demonstration Testing Results.

Application	Engine Type	Actual % of Time Above Required Temperature	Recommended % of Time Above Required Temperature
Camp Pendleton			
Ford L9000 truck	Caterpillar 3306	8% of time above 250ºC	8% of time above 250ºC
Thomas bus	Caterpillar 7.2L	Not tested	8% of time above 250ºC
International 7600 truck	Caterpillar C12	10% of time above 300ºC	7% of time above 300ºC
Ford F Series stake truck	Cummins C8.3-250	40% of time above 250ºC	8% of time above 250ºC
Cheyenne Mountain Air Force Station			
Thomas buses (2)	Cummins 5.9L	5% of time above 300ºC	7% of time above 300ºC
ATC			
Ford 350 pickup truck	Navistar 7.3L T44E	N/A*	7% of time above 300ºC
Navistar 4700 panel truck	Navistar 7.3L T44E	22% of time above 250ºC	8% of time above 250ºC

*This vehicle's normal reported duty-cycle was not captured during the test period, however, operating personnel provided an assessment that the exhaust gas stream was sufficiently hot to provide satisfactory filter regeneration.

The project team installed the pollution control technologies, including pressure and temperature instrumentation on each of the eight demonstration engines. The installations were performed in such a manner that the engines could be restored to their original configuration at the completion of the test periods. The retrofitted pollution control devices replaced the existing exhaust system mufflers. It was expected that each installation could be completed within one day and that all installations would be completed within a 3-month period. This expectation was met for the ESW filters, but not met for the RPF filters. Because of its additional hardware, the RPF installations took up to 2 days. For all the installations, the work was completed at the vehicle

operator's facilities. Each of the demonstration engines was operated for a period from several months to just over one year.

During the demonstration period, each of the test engines operated on their normal duty cycles. Since seven of the eight demonstration engines had a different cycle, a range of engine operating conditions was monitored during the demonstrations. In general, the vehicle operators were not aware that they were using a demonstration vehicle as the pollution control devices replaced the existing mufflers. The pollution control technology was designed to minimize its effect on engine performance and caused only minimal changes in engine noise, fuel economy, and power output.

3.5 SAMPLING/MONITORING PROCEDURES

Vehicle emissions measurements were made on one of the Cheyenne Mountain Air Force Station buses at the National Renewal Energy Laboratory (NREL) in Denver, Colorado, at the time the ESW filter was installed. Only one vehicle equipped with the ESW technology was emissions tested because of the significant cost of this testing. Emissions testing of an RPF-equipped vehicle was cancelled based on the factors described in Section 4.3. Measurements were made with the bus placed on a chassis dynamometer. Emissions testing was performed using both Fed EPA No. 2 (low sulfur diesel fuel no. 2 sold outside California and containing up to 500 ppm of sulfur) diesel fuel as well as B20 (20% biodiesel by volume, 80% petroleum diesel by volume) biodiesel. Two driving cycles were used. One cycle simulated the in-use bus cycle at Cheyenne Mountain Air Force Station (based on logged data taken from a bus while operating in the mountain), and the other cycle was a "standard" Central Business District (CBD) cycle used for buses. Measurements were taken by both the NREL emissions test facility and a transportable test facility operated by the University of California, Riverside (UCR). CO; CO_2; HC; nitrogen oxides chemical compounds, including NO and NO_2 (NOx); and PM measurements were taken by both organizations. HAP emissions measurements were only taken by UCR since the NREL equipment does not have this capability. The air emissions test results were reported as emission factors in grams per mile (g/mile).

In addition to characterization of emissions at NREL, exhaust temperatures and back pressures were measured and collected on each of the filters throughout the test periods. The ESW data was scanned every second and averaged and logged at a rate of one data set every 5 minutes. The RPF data was scanned every second and logged at a rate of one data set every 5 seconds. The temperature and pressure data was reviewed approximately monthly by project personnel to assess any irregularities or problems that might have arisen during the demonstration.

3.6 ANALYTICAL PROCEDURES

During the demonstration, engine exhaust gas temperatures upstream and downstream from the pollution control device were recorded using thermocouples. The history of the exhaust temperature was used to estimate the engine's duty cycle. The backpressure produced by the pollution control device was detected with a pressure transducer located on the inlet side of the filter.

Air pollution emissions testing of the Cheyenne Mountain Air Force Station bus for regulated pollutants (CO, HC, NOx, and PM) was performed using analytical test methods approved by

EPA and found in the CFR. Specifically, testing was performed using the methods contained in 40 CFR 86 for control of emissions from new and in-use highway vehicles and engines. The actual analytical testing instrumentation that was used for this project is listed in Table 4. For the nonregulated emissions, the analysis methods are not found in the CFR. Instead, these analyses were performed using industrial specifications and methods that are referenced in the scientific literature.

Table 4. Test Methods and Analysis of Exhaust Emissions.

Instrument/Method	Measurement	Sample Duration	Lower Quantifiable Limit (Expressed in terms of fundamental measurement)
Pierburg non dispersive infrared (NDIR)	CO_2, CO	1 second	50 - 500 ppm
California Analytical Instruments/flame ionization detection (FID)	HC, methane	1 second	10 - 30 ppm
California Analytical Instruments/chemiluminescence	NO, NO_2	1 second	10 ppm
Various/filter*	PM, mass and chemistry	0.25 - 2 hours	Various
Tedlar bag/gas chromatography (GC)-FID	Volatile organic compounds (VOC) ($C_2 – C_{12}$)	0.25 - 2 hours	10 parts per billion (ppb) C
Dinitrophenylhydrazine (DNPH) Cartridges/Shimadzu high performance liquid chromatography/ultraviolet (HPLC/UV)	Aldehydes and ketones	0.25 - 2 hours	0.02 µg/mL

*Includes Teflon and quartz media for mass, metals, ions, elemental/organic carbon and polycyclic aromatic hydrocarbons (PAHs) by gas chromatography/mass spectrometry (GC/MS) on extracts from filters.

Characterization of gaseous HAP compounds, including the mobile source air toxics identified in Table 5, were performed using GC where the samples were collected on DNPH cartridges. Acetaldehyde, formaldehyde, benzene, and 1,3-butadiene are the four main gas-phase HAPs specified in the CAA for mobile sources. Acrolien is another gas-phase chemical targeted by EPA for its toxicity and ambient levels. Naphthalene is the PAH with the highest concentration in vehicle exhaust.

Table 5. Partial List of EPA's Recognized Mobile Source Air Toxics.

Acetaldehyde	1,3-butadiene
Acrolein	Formaldehyde
Benzene	Naphthalene

The measurement of PM emissions is more difficult and consisted of mass measurements as well as chemical characterization of the particles. Mass measurements were made by collecting particulates on a filter media and weighing the media before and after exposure to the exhaust. For these measurements, it is critical that the CFR methods be applied with respect to the use of an upstream classifier to remove the large particles and that the filter face temperature be maintained at 47°C ±5°C. Chemical characterization of the PM involved chemically testing the particles collected on quartz filter media for elemental and organic carbon, as these measurements can be directly related to the information gained with the ambient PM monitors.

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4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

The ESW filter performed very well during this demonstration test. This device was easy to install and maintain over the test period. Reported drivability issues were minimal. The filter provided the required results of reducing air pollution emissions and reducing PM emissions by 50% while maintaining the backpressure on the engine between the required limits of 20 to 34 kPa. The technology proved itself sufficiently robust for long-term, trouble-free use. Use of the filters did not significantly affect the vehicle's fuel economy (FE). In summary, the ESW filter met all performance acceptance criteria identified in Table1.

The RPF filter, on the other hand, did not perform satisfactorily. The drivability, installation, and reliability performance objectives were not met. Neither the emissions control nor fuel economy performance objectives were measured since the other performance metrics were not met and since the emissions testing is very expensive.

A summary of the mileage accumulated on each vehicle during the demonstration period is included in Table 6. Examples of some UCR-measured air pollutant emissions measurements are shown in Figures 3 and 4. Multiple emissions measurements were performed at each test condition. Error bars on the figures reflect uncertainties in the measurements. In the first figure, bar charts identifying criteria air pollution emissions factors in g/mi and fuel economy in miles per gallon are shown. Charts are included for a multitude of biodiesel and diesel fuels, both with and without an ESW filter installed. To incorporate data for different pollutants on the same plot, the results for non-methane hydrocarbons (NMHC), total hydrocarbons (THC), and PM are plotted with a factor of 10 multiplier.

Table 6. Mileage Accumulation of Test Vehicles.

Technology	Location	Vehicle Description	Vehicle No.	Installation Completion Date	Vehicle Mileage at End of Test	Date Data Collection Ended	Total Miles Accumulated
ESW particulate reactor	Cheyenne Mountain	Thomas bus	USAF 001587	3/22/05	82,871	6/30/06	18,189
	Cheyenne Mountain	Thomas bus	USAF 001589	3/10/05	60,057	6/30/06	22,400
	Camp Pendleton	ITEC 7600 truck	291915	5/17/05	111,725	8/9/06	43,965
	Aberdeen Test Center	Ford 350 pickup	AC 6384	6/2/05	95,861	7/28/06	13,861
						Total	**98,415**
CES* robust particulate filter	Camp Pendleton	Ford L9000 truck	MC 288060	8/18/05	400,000	6/17/06	15,022
	Camp Pendleton	Ford F900 truck	C 291496	8/26/05	92,460	5/18/06	1,772
	Camp Pendleton	Thomas bus	G 3200583	9/1/05	185,555	8/3/06	27,465
	Aberdeen Test Center	IH 4700 truck	G71-01456	4/1/06	18,336	6/30/06	358
						Total	**44,617**

*CES = Cummins Emissions Solutions

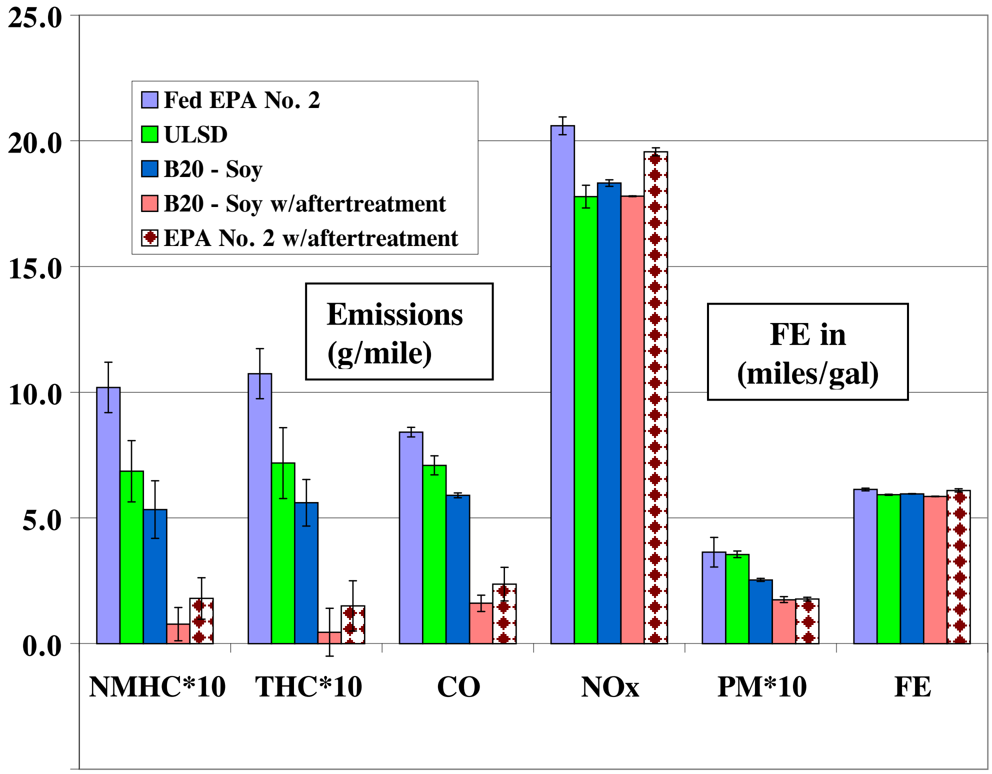

Figure 3. UCR Results for Cheyenne Mountain Operating Cycle.

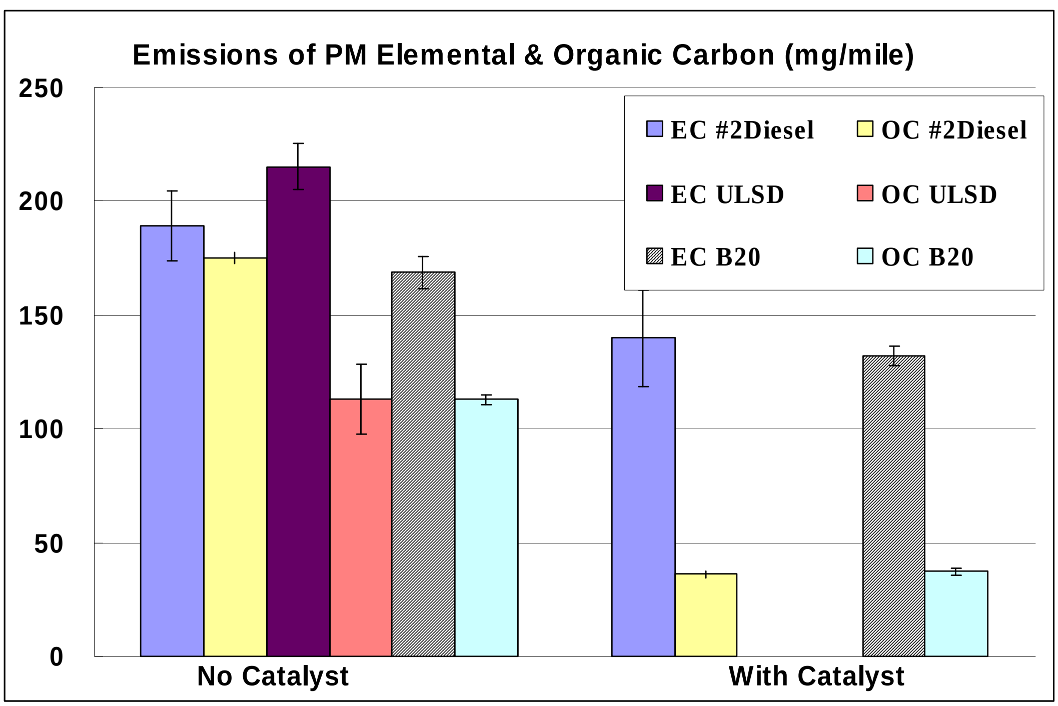

Figure 4. URC Results for Elemental and Organic Carbon for the Cheyenne Mountain Operating Cycle.

Figure 4 provides similar results for elemental and organic carbon. Again results are provided for a multitude of fuels both with and without the filter installed. The results for organic carbon can be used as a surrogate for HAP emissions since the organic carbon measurement includes HAP compounds.

Both the criteria and HAP emission factors shown on Figures 3 and 4 were measured using transient chassis dynamometer testing conducted at the NREL ReFUEL laboratory. The results shown on these figures were from a custom developed driving cycle for a Cheyenne Mountain Air Force Station operated bus. The transient test was designed to specifically simulate operation of the buses within Cheyenne Mountain. The Cheyenne Mountain cycle is shown in Figure 5. This cycle was developed based on activity data monitored from actual buses operating within the Cheyenne Mountain facility. It is composed of six primary events where the vehicle is accelerated to a speed of 20 to 32 miles per hour (mph). A total of 2.5 miles are driven over a 1,200 second duration. On the figure the standard recognized CBD transient cycle is also shown for comparison.

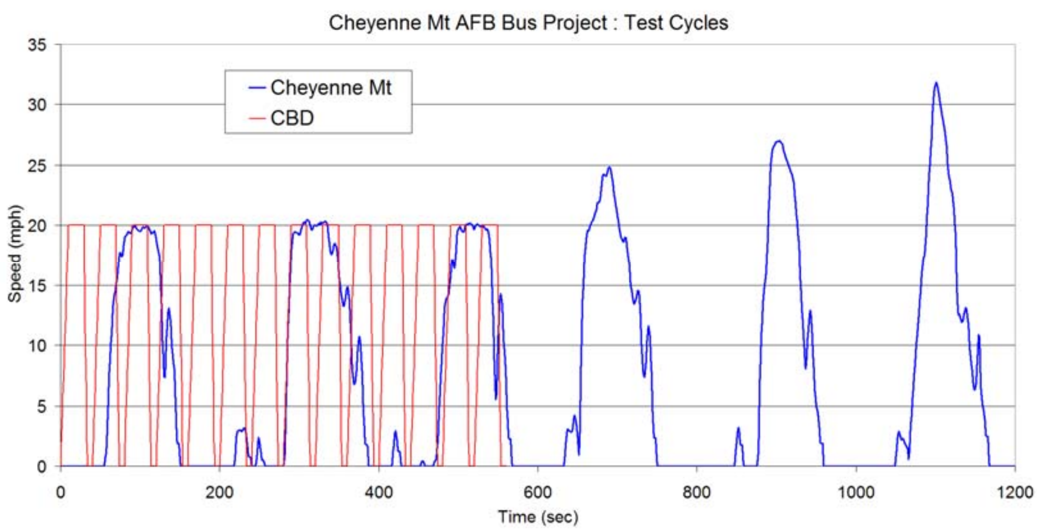

Figure 5. Plots of Cheyenne Mountain Operating Cycle and Reference CBD Driving Schedule.

4.2 PERFORMANCE CRITERIA

Table 7 provides the performance criteria established in the demonstration plan. The actual demonstration results have been incorporated into the table. For the ESW filter, the performance criteria were met, while for the RPF filter, the criteria were generally either not met or not measured. Qualitative criteria such as drivability and reliability were evaluated by discussion with demonstration site personnel. Hardware installation efforts were accessed by the project team. Regeneration performance for the ESW filter was determined by examining the backpressure data collected during the field test. For the RPF filter, regeneration performance was determined by using the filter delta pressure to calculate soot loading. For the quantitative air pollution emissions performance criteria, the actual performance is reported based on the test results while using Fed EPA No. 2 since this was the fuel in use at the time the Cheyenne Mountain Air Force Station demonstration was begun. Emissions testing with this fuel was

completed using only the Cheyenne Mountain operating cycle. The testing using the CBD driving cycle was performed using only B20 biodiesel. Since there are numerous HAP compounds, an average of the elemental and organic carbon emissions reductions are reported as the actual performance.

Table 7. Expected Performance and Performance Confirmation Methods.

Performance Criteria	Expected Performance (pre demo)	Performance Confirmation Method	Actual Performance (post demo)
Primary Criteria (Performance Objectives) (Quantitative)			
Backpressure	34 kPa max.	Pressure transducer	ESW – 33.9 kPa max Average for 9 data sets was 2.0 kPa RPF – Average ΔP was 5 kPa
CO emissions	Reduce emissions by 60% minimum	40 CFR 86	ESW – 68% reduction RPF – Not measured
Fuel economy	Achieve fuel penalty of less than 2%	40 CFR 86	ESW – No fuel penalty RPF – Not measured
HC emissions	Reduce emissions by 60% minimum	40 CFR 86	ESW – 82% reduction RPF – Not measured
PM emissions	Reduce emissions by 50% minimum	40 CFR 86	ESW – 50% reduction RPF – Not measured
HAP emissions	Reduce emissions by 50% minimum	Various EPA methods	ESW – 53% reduction RPF – Not measured
Primary Performance Criteria (Qualitative)			
Drivability	No change	Driver response	ESW - One driver complaint—resolved RPF – No complaints reported
Installation	Easy retrofit on existing DoD diesel engines	Mechanic response	ESW – All installations easily completed within one day RPF – Difficult two-day installations. For Ford F900 truck, specialized exhaust system fabrication equipment was required
Reliability	No change	Mechanic response	ESW - No breakdowns RPF – Several breakdowns of Ford F900 Truck caused by high soot loading faults

4.3 DATA EVALUATION

All ESW filters performed as expected, despite the fact that for three of the vehicles, the filter inlet temperatures were generally lower than that prescribed by the manufacturer, thus indicating that the vehicles were experiencing light-duty cycles. No occurrences of excessive backpressure were observed. High backpressures are indicative of high filter soot loading, filter plugging and insufficient filter regeneration events. This is important because high backpressure significantly reduces the engine performance and increases fuel consumption. Emissions testing on the Cheyenne Mountain Air Force Station bus showed a 50% reduction in PM emissions and a greater than 50% reduction in CO, HC, and HAP emissions. No special training was needed for use of the ESW filter. Also, there were no special health and safety requirements. There was one

operator concern regarding drivability and one equipment failure due to a pressure sensor inlet tube becoming fouled. There were no reported failures of the ESW filter itself.

Of the four RPF test vehicles, the Thomas bus and the Ford L9000 truck had sufficiently high duty cycles (i.e., load factors) that the technology's active regeneration capability was only marginally demonstrated. For these vehicles, passive regeneration was sufficient to control filter soot loading and thus backpressure. The systems operated as designed with no component failures. Looking back, the selection of these test vehicles was probably a poor choice given their marginal need for active regeneration.

For the other two test vehicles, low-duty cycles (i.e., engine load factors) make active regeneration a necessity. While these vehicles periodically produced engine exhaust gas temperatures sufficiently high to initiate "active" filter regeneration, "active" regeneration often did not occur when needed. Despite the various controls accompanying this technology (i.e., fuel dosing, exhaust throttle valve, and pressure measurement/control), the filter electronic control module (ECM) was often not permitted by its programming to initiate fuel dosing when "active" regeneration was scheduled. One of the reasons for this problem was that the computer programming required for the system to operate in the fully automatic mode proved to be much more difficult than initially envisioned. The project team could not resolve these programming problems given the project's time and budget constraints; instead, the decision was made to operate the system in a time-based mode. By using this mode, regeneration events were set to occur at specified time intervals that were based on engine duty cycle information. Regeneration at these specified times would only occur if the engine gas temperature was above the 288°C minimum set by the system. Since most of the time, the temperature conditions were not met at the scheduled regeneration times, inadequate active regeneration occurred. This lack of regeneration led to very high filter soot loading and to several system faults (on the Ford F900) that required servicing. It is obvious that for the RPF technology to operate satisfactorily on a wide range of potential retrofit applications, special exhaust gas thermal management techniques, including the addition of an intake throttle and possibly new electronic engine controls, must be developed to ensure that the engine gas temperature can be maintained above the 288°C fuel dosing threshold when regenerations are required.

Based on these difficulties and a market analysis, Cummins decided not to develop this technology for the retrofit market. Other manufacturers are, however, developing similar technologies. Based on our experience, the project team would recommend being very cautious prior to installing such a technology on a DoD-operated engine.

4.4 TECHNOLOGY COMPARISON

The technologies demonstrated by this project were developed to address new air pollution emission reduction regulations promulgated by both the EPA and CARB. The vast majority of the existing DoD diesel-powered vehicle fleet is not equipped with an exhaust aftertreatment device. Starting with the 2007 model year, all new on-road diesel-powered vehicles are being delivered with a CSF installed in order to reduce PM emissions by 90%. Depending on the application, some of these devices operate passively, using only the heat of the exhaust. Other devices, like the RPF filter, use a supplemental heat source such as fuel injection into the exhaust system.

Given that the ESW filter is a CARB Level II certified particulate and emissions control device, it is not suitable for the 2007 new on-road market. Instead, it has particular value in the retrofit or new off-road market. In general, the ESW filter will directly compete with other CARB Level II certified aftertreatment devices.

5.0 COST ASSESSMENT

5.1 COST REPORTING

In this section only the costs associated with the ESW technology will be discussed since the Cummins RPF technology is not recommended for implementation within DoD. It is expected that the ESW technology demonstrated during this project will be suitable for a number of types and sizes of DoD diesel engines and that costs for its implementation will vary with the size of the engine, expected engine duty cycle, difficulty of hardware installation, and the number of similar units installed. Assessment and analysis of costs associated with implementation of the ESW filter are given in Table 8. These costs were developed assuming an on-road diesel-powered heavy-duty vehicle such as a truck driven 16,000 miles annually with an engine size of 6 to 7 liters displacement.

Table 8. Types of Costs by Category.
(Truck with 6-7 liter engine)

Direct Environmental Activity Process Costs				**Indirect Environmental Activity Costs**		**Other Costs**	
Start-Up		**Operation & Maintenance**					
Activity	$	Activity	$	Activity	$	Activity	$
Equipment purchase	4,200 to 5,400	Maintenance	0	Fuel mileage penalty	0	None	0
Installation	400 to 600						

The capital costs for the ESW filter are dependent on the size and use of the engine. If a number of similar units are installed/ordered simultaneously, a reduced unit cost can usually be negotiated. The needed physical size and exhaust handling capacity of the filter increases with the size and loading of the engine. Larger filter units are more costly, and a system must often be custom-designed and manufactured for an application for the filter to both fit into the available installation space on the vehicle as well as satisfactorily handle the exhaust gas flows. The uniqueness of a design can affect the cost of a unit significantly, leading to cost discounts when several filters of a type are purchased. Pricing for the filters themselves and installation costs were provided by International Truck and Engine Corporation, the current distributor for the ESW filter. It is expected that filters will be installed by the distributor's mechanics.

In general, the service life of exhaust gas filter technologies is only marginally dependent on vehicle age. Of greater importance is the vehicle mileage/engine operating hours. From preliminary research, CES estimated that the service life of the ESW filter will be equal to or greater than the diesel engine service life for most DoD applications.

While annual filter cleaning is not normally required, ESW recommends that the filter should be periodically visually inspected. During engine operation, the only action required of an operator is to periodically monitor an indicator light on the vehicle control panel that warns of excessive

filter backpressures. In the event that this light becomes lit, the operator should report this to the maintenance department so the filter can be cleaned.

5.2 COST ANALYSIS

Since the purpose of this ESTCP compliance project is to meet proposed future diesel engine PM emissions-reduction retrofit requirements, all costs associated with the development and implementation of the demonstrated technologies represent new costs. Only in the past year have EPA regulations begun to require the use of exhaust aftertreatment technology for new vehicles. The required retrofit of existing engines with exhaust filters is now just starting in California.

Other than the ESW technology demonstrated in this project, other technologies have also been approved by CARB and EPA to reduce diesel engine PM emissions. However, all these technologies are relatively new, and cost and performance information for them is limited. An additional consideration is that most of these technologies require the use of ULSD fuel (<15 ppm).

The ESW technology has no expected operational or maintenance costs. For most potential DoD applications, the hardware is expected to last the life of the diesel engine. The total implementation costs will therefore include only the hardware purchase and installation. The purchase cost depends on the engine size, engine duty, and the number of equivalent systems to be manufactured. The installation costs will vary depending on the difficulty of the installation.

Based on the above, the life-cycle cost for implementing the ESW technology is expected to be \$4,200 - \$5,200 for the equipment plus \$400 - \$600 for installation, resulting in a total cost of \$4,600 - \$5,800 for a typical installation. This cost may increase/decrease based upon the size and use of a particular application and the number of similar units purchased.

5.3 COST COMPARISON

To compare the ESW unit to competing technologies, data on all diesel aftertreatment CARB Level II certified particulate filters applicable to on- or off-road diesel engines is shown in Table 9. The data compares unit cost, installation cost, fuel requirements, and percent PM emissions reduction.

Table 9. Comparison of ESW Filter with Other Technologies.

Technology	Unit Cost	Installation	Fuel Requirement	Emissions Reduction
ESW particulate reactor	\$4,200-\$5,400	\$400-\$600, 8hrs	Low sulfur diesel (<500 ppm)	~50%
Engine Control Systems AZ purimuffler/purifier	~\$1,000	Unknown	PuriNOx (proprietary water /diesel emulsified fuel)	~50%
Donaldson DMF muffler	\$6,000 - \$8,000	Included, 1-3 hrs	Ultra low sulfur diesel (<15 ppm)	71-75%

The cost of the ESW filter is somewhat less than that of the Donaldson filter; however, the ESW device can be used with fuel sulfur levels as high as 500 ppm (low-sulfur fuel). This can be an important advantage for some off-road applications where ULSD fuel is not required. The Donaldson muffler is, however, reported to reduce the PM emissions by 70% compared to 50% for the ESW product. The Engine Control Systems filter is considerably less expensive; however, it reduces PM emissions by only 40% unless the proprietary PuriNOx (proprietary water/diesel emulsified fuel) is also used.

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

There were many factors that significantly affected the final cost of this project. The primary factors were the number of demonstration engines, the number of test sites, the length of the demonstrations, the extent of emissions testing and the number of demonstration technologies. Unfortunately, the financial control system used to account for the project costs was not of sufficient sophistication in order to associate project costs with these cost factors.

Overall, the project was completed within the originally approved budget. This performance was achieved even with an increase in the scope of the project. The reason that the additional work could be added without any additional costs was due to the free emissions testing performed by the National Renewable Energy Laboratory. In addition, the project's industrial partner, Cummins, contributed more resources than originally committed.

For future installations, some reduction in costs is expected. During this project, the project team monitored filter performance on a monthly basis. This will not be done in the future. Also, as the market for diesel filters develops, it is expected that their costs will decrease and the engineering efforts required for installation will be reduced. As more manufacturers enter the diesel retrofit market, it could be expected that competition will further lower customer prices.

6.2 PERFORMANCE OBSERVATIONS

For the ESW filter, all emissions reductions, drivability, installation, and reliability performance objectives in Table 1 were met. For the RPF filter, the drivability, installation, and reliability performance objectives in Table 1 were not met. The emissions control performance objectives for the RPF filter were not measured since the other performance metrics were not met.

6.3 SCALE-UP

For this project, full sized engines commonly found at DoD facilities were used for the demonstration. For future installations, it is expected that similar types of engines with similar duty cycles will be used. Scale-up should therefore only involve placing the filters on a larger number of engines.

At this time, the filters are still being custom manufactured for each job. It is expected that as the market develops, filters will be readily available in most of the sizes applicable to common DoD engines. Along with this increased availability, the filter costs should also decrease.

6.4 OTHER SIGNIFICANT OBSERVATIONS

Except as otherwise discussed in this and the final report, the project team is not aware of other major factors that can affect implementation of the technology. For situations where implementation is optional, the total cost for implementation will be the driving factor.

6.5 LESSONS LEARNED

For the ESW filter, the test results reported in this report are very positive in the sense that the filter reduced pollutant emissions as reported by its manufacturer and performed essentially maintenance-free during this project. One must always keep in mind, however, the engine duty cycle operational limits for the filter and try to ensure that your vehicle will be operating within those limits. The fine performance of the ESW filter during these tests, even at temperatures below those recommended by the manufacturer, should not lead one to stray too far outside of those recommended limits.

For the RPF filter, on the other hand, this project showed that effective operation of this type of "active" Level III filter requires close coordination between the engine ECM and the filter ECM to accomplish effective "active" filter regeneration. The tests showed that use of filters that were not fully automatic was problematical, and the difficulty of implementing less-than-fully-automatic Level III devices for retrofit applications was demonstrated. These results illustrate the practical problems of imposing the complexities of Level III filters on a broad spectrum of vehicles and operators. Rather, a device such as the ESW filter, which our tests have shown operates quite well and without difficulty over extended engine operational regimes, is easy to install and operate, is effective (50% PM reduction), and may be a very good and inexpensive alternative.

6.6 END-USER/ORIGINAL EQUIPMENT MANUFACTURER (OEM) ISSUES

The end users of the results of this project will be DoD diesel-powered fleet and equipment operators. The primary concerns of these end users will be obtaining and operating exhaust gas treatment technologies approved by environmental regulators to meet current and newly enacted air pollution compliance requirements for the lowest life-cycle costs. To ensure that the ESW filter technology demonstrated by this project is approved for use by potential DoD customers, it will need to be EPA or CARB certified. Currently, the ESW filter has been CARB qualified as a Level II (PM reductions of 50%) exhaust gas treatment device for older (1991–1997) engines, and CARB considers it to be the "best available control technology" for them. To be certified as a Level II device for newer engines, it will need further qualification testing.

To ensure that project results are quickly transitioned to potential DoD customers, the transition plan for this project will focus on directly assisting the DoD fleet managers within California to comply with the recently approved CARB regulation to retrofit off-road diesel vehicles. This regulation requires that by the end of the year 2010, all DoD diesel off-road vehicles be retrofitted with the "best available technology" (BAT). In many of these DoD applications, the ESW technology will be the BAT. The NAVFAC Engineering Service Center has been working with the California DoD Air Team to ensure that a consistent implementation strategy is followed.

To further publicize the test results in various forms readily available to DoD, the NAVFAC Engineering Service Center will ensure that project results are published in NAVFAC Fact Sheets and a technical report as well as a *Currents* magazine article. Project results will also be posted on the Defense Environmental Network & Information Exchange (DENIX) Web site.

In addition to the potential need in support of environmental compliance, the NAVFAC Engineering Service Center will also work with ESW to promote the use of its technology for tactical application where high sulfur fuel is used. Although tactical vehicles are not required to meet air pollution control standards, there is a significant tactical advantage of reducing black exhaust smoke. So far, the technology has already been implemented on a new Marine Corps Light Armored Vehicle Program. In addition, information on the ESW technology has been passed on to other tactical vehicle program offices.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

For this project, the PM filters were installed in place of the existing engine mufflers. Since no part of the existing engine pollution control systems were changed, the project was completed without obtaining an environmental air permits nor the approval of an environmental regulatory agency. To fully implement the technology within DoD, however, local air pollution control authorities approvals will be required. It is expected that the main DoD applications for the ESW technology will be to retrofit existing engines in response to regulations such as those already promulgated by CARB. To satisfy these regulations, the local air pollution control authorities must agree that the ESW technology represents the BAT for the particular application.

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7.0 REFERENCES

Naval Facilities Engineering Service Center Technical Report TR-2223-ENV, *Reduction of Diesel Engine Particulate Emissions Using a Self-Regenerating Soot Filter*, June 2003.

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APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization	Phone Fax E-Mail	Role
Dr. Norman Helgeson	NAVFAC ESC 1100 23rd Avenue Port Hueneme, CA. 93043	Phone: 805-982-1335 Fax: 805-982-4832 E-Mail: norman.helgeson@navy.mil	Principal Investigator
Bruce Holden	NAVFAC ESC 1100 23rd Avenue Port Hueneme, CA 93043	Phone: 805-982-6050 Fax: 805-982-4832 E-Mail: Bruce.holden@navy.mil	Technology Implementation
Patrick Pierz	Cummins Inc., Fleetguard Emission Solutions Business 1900 McKinley Avenue MC: 50183 Columbus, IN 47201	Phone: 812-377-7217 E-Mail: patrick.m.pierz@fleetguard.com	Project Manager for Cummins, Inc.
David Trueblood	Cole Technologies 3360 Commerce Drive Columbus, IN 47201	Phone: 812-378-0678 Fax: 812-377-8214 E-Mail: dave.trueblood@Fleetguard.com	Consultant for Cummins, Inc., Fleetguard Emission Solutions Business

ESTCP Program Office

901 North Stuart Street
Suite 303
Arlington, Virginia 22203

(703) 696-2117 (Phone)
(703) 696-2114 (Fax)

e-mail: estcp@estcp.org
www.estcp.org